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EFFECT OF A VENTED EXPLOSIVE BLAST ON THE FRANGIBLE PANEL OF A NEIGHBORING CUBICLE

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ABSTRACT

This paper addresses the problem of designing the frangible panels in a row of cubicles for the blast load produced by an accidental explosion in a neighboring cubicle. This panel has to withstand the external load of the vented blast in order to maintain the protective function of the structure. To determine the load, a 3D hydrocode is used to obtain a numerical solution of the internal and external flow fields produced by an explosion in an adjoining cubicle. The calculation was carried out to 120 ms for a typical cubicle of 6.5x7.0x5.2 meters, assuming a charge of 24 kg. The results are compared with predictions obtained from commonly accepted design manuals.

1. INTRODUCTION

In practice, the design of protective structures relies heavily on semi-empirical and experimental data collected by workers in the field. The main source of data and methodology is the American Tri-Service TM 5-1300 manual [1]. For vented structures, with or without frangible panels., References [2-4] furnish experimental data obtained by the Naval Civil Engineering Laboratory (NCEL). Some simplified mathematical models for the effects of frangible panels may be found in [5]. A recent study combined theoretical and experimental results and reduced them to a single "working curve" employing similarity methods [6].

In recent years the use of detailed flow calculations for determining the loads on structures has become more tractable, due to the new generation of cost efficient computers. In addition, more accurate numerical methods for simulating blast wave propagation were developed. As a result, the use of numerical codes (usually called hydrocodes) has become a viable tool for assessing blast loads on structures. References [7-10] are typical examples of this approach. Using a hydrocode, the complex

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flow fields created by internal explosions may be treated. Such flow fields may include wave reflections and diffraction by solid obstacles, and blast wave venting through openings. These capabilities enable the protective structure designer to optimize the structure and thus avoid a costly overconservative design.

In the present work we employ the DYTRAN program for studying the response of a frangible panel to the vented blast wave created by an explosion in an adjoining cubicle. This problem appears in the design of multi-bay munition production plants. A basic safety requirement in such plants is provided by frangible panels, which allow venting of the blast wave resulting from an accidental explosion. Typically, frangible panels have low areal weight and are weakly connected to the main structure. This connection is designed to provide a minimal resistance to the venting of the blast wave, in order to relieve the internal pressure as quickly as possible. In the case of multi-bay plants, the designer has to consider also the external load created by the vented blast wave from an adjoining bay. Thus, the connection of the frangible panel to the main structure has to be asymmetric with respect to the load direction, in order to act properly against both loads.

The data provided by the design manual [1] for the internal blast load on the frangible panel is adequate for cubicles with regular shapes. However, for the vented blast load on an acceptor panel only a simple generic case is given, namely an explosion within an uncovered cubicle. The problem under consideration here deals with a covered cubicle. In addition, there is a significant separation between the cubicles (see Figure 1), which makes the application of the manual generic case very doubtful. We were thus led to employ numerical codes for determining the load on the acceptor panel for our particular design.

In the following section we will describe the multi-bay plant in a schematic manner. Section 3 will present the computational model used for determining the loads. Section 4 will be devoted to a simlified model of the explosive charge. In section 5 the results of the calculations will be presented, together with a comparison against the manual predictions. A short summary and conclusions are given in Section 6.

2. STATEMENT OF PROBLEM

The multi-bay production plant is shown schematically in Figures 1a-c. It is assumed that an explosive charge of 24 kg is detonated at the middle of the center bay (the donor cubicle). As a result, the frangible panel is blown out and the escaping blast wave diffracts over the separating walls and hits the frangible panels of the adjoining cubicles. The load on the acceptor frangible panels is required for the design of the structural attachment of the panels to the main building.

3. COMPUTATIONAL MODEL

The computational model employs the Euler solver of the MSC/DYTRAN code [10] to represent the flow of the detonation products and the ambient air. The moving parts in the computational model (frangible panels and external rain roofs) interact with the flow field by a general coupling algorithm which creates the necessary flow field boundaries imposed by the moving parts, while applying the appropriate forces on the moving parts, generated by the surrounding flow. The explosive charge was

represented by its mass and energy, as will be described in section 4. The charge is assumed to be located at the center plane of the cubicle. This assumption allows as to define a vertical symmetry plane passing through the center of the charge, so that only one symmetrical half of the plant needs to be modeled. The walls of the cubicles (Fig.1) were modeled as rigid wall, since they are not expected to deform significantly.

The frangible panel in the donor cubicle was modeled as a thin partition consisting of one element across the thickness. The lower edge of the partition was constrained from moving out of the floor plane. The frangible panel in the acceptor cubicle was modeled as a rigid body, constrained to move in a direction normal to its surface. This simplified modeling was adopted since this study was aimed at getting a first estimate of the total impulse on the acceptor panel, for comparison with the manual predictions. A more refined modeling in the future will enable us to obtain the details of the structural response of the panel for evaluation. Similarly, the roofs were modeled as rigid bodies constrained to move vertically.

The entire problem is embedded in a parallelopiped of 15.0m x 12.5m x 9.36m, consisting of 30x25x18 elements. This mesh was judged sufficiently large for accomodating the blast venting to the open air, neglecting the effects of a nearby sand mound. Figure 2a shows the rigid walls as shaded surface
elements, without the panels and roofs, for the sake of clarity. Figure 2b shows the model with the panels and roofs included.

4. REPRESENTATION OF THE EXPLOSIVE

When modeling the detailed interaction of a high explosive with an adjacent material, it is important to represent the correct shape of the explosive charge and to simulate adequately the detonation process. In blast wave modeling, however, the exact shape of the charge and the details of the detonation process have a small effect on the blast wave characteristics at large distances from the explosive.

To simplify the present calculation, we represent the explosive charge by a small volume of a "hot gas", with the correct mass and energy. The gas is assumed ideal, so that the only material property that remains to be chosen is the ratio of specific heats, Γ. A typical value of Γ for the detonation products at low pressure would be about 1.3. For further simplification of the problem, we use the same Γ value as for air, i.e. 1.4. In this way the Euler flow calculation involves a single material. Based on previous works, this simplification affects the blast wave impulse by less than 5%, which is of the same order of magnitude of the uncertainty in the explosive energy.

The uncertainty in the explosive chemical energy may be judged from the range of values reported by two references. In Ref.[11] we find a value of 4.3 MJ/kg for TNT, compared with 4.1 MJ/kg given by ref.[12]. We adopt a value of 4.2 MJ/kg. The density of TNT is about 1630 Kg/cu.m. This initial high density makes the volume of the "hot gas" region very small in terms of the number of Euler elements. For 24 kg of charge, the volume would be a cube with a side of approximately 0.25 m. Since 'the computational cells used in the calculation have a typical dimension of about 0.5m, the entire charge would occupy less than one cell, if the actual density is maintained. To circumvent this problem, a smaller density is chosen as initial density for the "hot gas" region, so that the charge would occupy

just one element. It turned out that this initial density was around 100. kg/cu.m. The effect of a lower charge density was studied in [83. It was found that an 8-fold increase of the density from 25. to 200. kg/cu.m. amounted to less than 5% difference in the blast impulse on the structure. Thus the above choice of the initial density is satisfactory.

5. RESULTS AND DISCUSSION

The results of a 3D calculations can be displayed in a variety of ways. In the present case we are interested mainly in the motion of the frangible panels and roofs. Their position at time of 100. ms is shown in Figure 3.

The central objective of the calculation is the load on the acceptor panel. Instead of showing the pressure time histories at various points on the panel, we will consider the average load on the entire panel. The effect of this load may be evaluated from the panel motion as a rigid body. Figure 4 shows the panel velocity time history. Acceleration starts around 28 ms, and the panel moves inwardly until about 54 ms, when the panel reaches its top velocity of 11 m/s. The panel then decelerates and subsequently acquires an outward velocity. This outward motion is a result of the suction phase of the blast wave. A small contribution to the outward motion results from the internal overpressure created by the moving panel, which acts like a piston, compressing the air inside the cubicle.

The specific average impulse of the positive phase of the load may be estimated from the peak velocity and the panel areal density of 10 kg/sq.m. The result is:

$$I = 110 \text{ Pa-sec} = 110 \text{ kPa-ms}$$

A peak overpressure may be estimated from this impulse assuming that the main acceleration took place over a period t of 22 ms. The result is:

$$Pm = 2 I / t = 10 \text{ kPa} = 0.1 \text{ bar}$$

The total impulse on the frangible panel is obtained by multiplying the impulse per unit area by the panel area of 5.2m x 7.0 m. The panel impulse value is:

$$I = 4.0 \text{ kN-s}$$

It is interesting to compare the above results with the TM 5-1300 manual predictions. Section 2-14.4 of the manual deals with leakage pressures from vented cubicles. The data given pertains to a generic configuration of a fully vented three wall cubicle with roof. Our configuration differs from the generic configuration mainly by the presence of the separation walls, which protrude a significant 3.1 m (about half the cubicle depth). This separation wall diffracts the blast wave to the extent that a portion of the acceptor panel would be obscured from its effect. A very rough estimate of the load on the panel may be obtained assuming that one half the panel is not loaded at all, and the other half is loaded by the blast wave that would be generated if the separation wall was absent, see Figure 3. The impulse at the

representative point B (at the middle of the loaded half) would be about 225 kPa-ms. The total impulse would be obtained, according to the present estimate, by multiplying this value by half the panel area. The result is:

$$I = 4.1 \text{ kN-s}$$

This value is very close to the hydrocode calculated value. It is worthwhile to note that if one uses the manual data disregarding the separation wall, one would obtain an an average impulse per unit area of 277 kPa-ms.

The total impulse on the panel would then be obtained by multiplying this value by the total panel area. The result is:

$$I = 10.1 \text{ kN-s}$$

Using this value for design would result in an overconservative design. The separation wall may therefore be regarded as an effective means for reducing the loads on a neighboring cell.

6. SUMMARY AND CONCLUSIONS

The paper presented a numerical solution of the blast wave generated by an explosion within one cubicle in a multi-bay production plant. The solution was used to detrmine the leakage pressure load on a the frangible panel of a neighbor cubicle. It was found that the protruding separation walls used in the present design are very effective in reducing the load on neighboring cubicles.

REFERENCES

[1] "Structures to Resist the Effects of Accidental Explosions"., Army TMS1300, Dept. of the Army, Navy and Air Force, Wasington D.C., Nov. 1990.

[2] Keenan, W.A. and Tancreto, J.E.: "Blast Environment from Fully and Partially Vented Explosions in Cubicles", Tech. Report 51-027, NCEL, Port Hueneme, CA., (1974).

[3] Keenan, W.A.. and Tancreto, J.E.: "Design Criteria for Frangible Covers in Ordnance Facilities", Proceedings of the 20th DoD Explosives Safety Seminar, p.333-362, Norfolk, 1982.

[4] Tancreto, J.E. and Helseth, E.S.: "Effects of Frangible Panels on Internal Gas Pressures", Proceedings of the 21st DoD Explosives Safety Seminar, p.365-394, Houston, 1984.

[5] Kulesz, J.J. and Friesenhahn, G.J.: "Explosion Venting in Buildings", Proceedings of the 19th DoD Explosives Safety Seminar, p.413-428, Los -Angeles, CA., 1980.

[6] Andersen, C.E. et al.: "Quasi-Static Pressure, Duration, and Impulse for Explosions in

Structures", Int. J. Mech. Sci.,Vol.25,No.6,p.455-464, 1983.

[7] Gregory, F.H.: "Analysis of the Loading Response of a Suppressive Shield when Subjected to an Internal Explosion", Proceedings of the 17th DoD Explosives Safety Seminar, p.743-760, Denver, 1976.

[8] Kivity, Y. and Feller, S.: "Blast Venting from a Cubicle", Proceedings of the 22nd DoD Explosives Safety Seminar, Anaheim, CA., 1986.

[9] Kivity, Y. and Kalkstein, A.: "Blast Wave Penetration into Cubicles", Proceedings of the 23rd DoD Explosives Safety Seminar, Atlanta, GA., 1988.

[10] Kivity, Y., Florie, C. and Lenselink, H.: "Response of Protective Structures to Internal Explosions with Venting", Proceedingds of the MacNeal-Schwendler Company World Users' Meeting, Arlington, VA., 1993.

[11] Dobratz, B.M., "LLNL Explosives Handbook". Lawrence Livermore National Laboratory report UCRL-52997, March 1981.

[12] Johansson, C.H. and Persson, P.A.: "Detonics of High Explosives", Academic Press (1970), Table 1.1.1, p.9.

Figure 1a: Layout of the Multi-bay production Plant

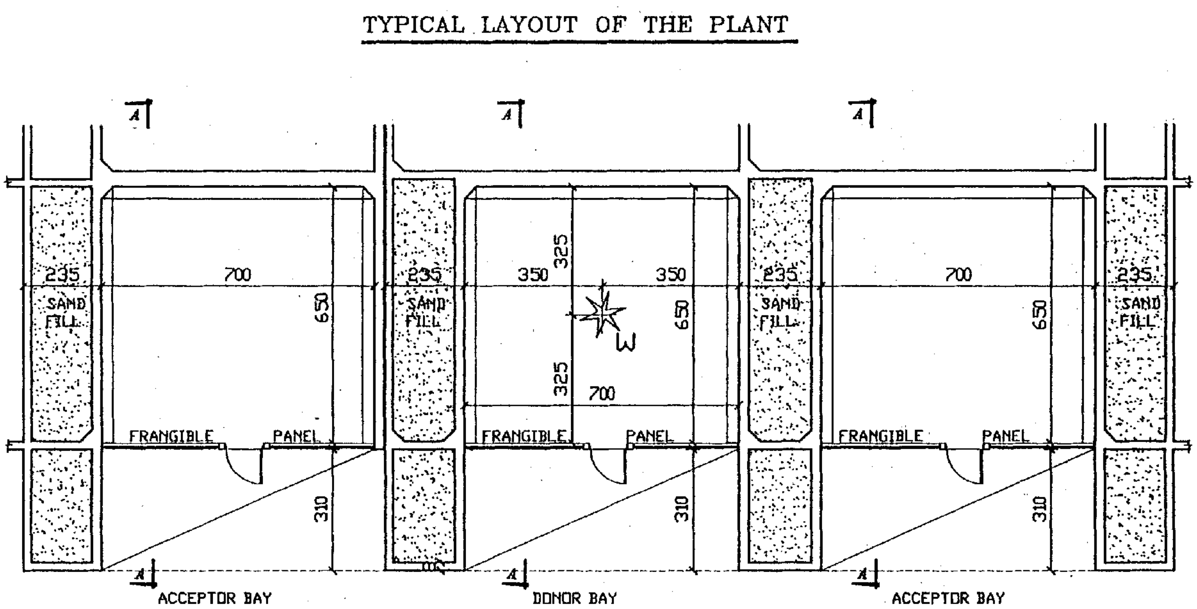

FIGURE 1a : LAYOUT OF THE MULTI-BAY PRODUCTION PLANT

Figure 1b: Layout of the Simulated Symmetrical Half

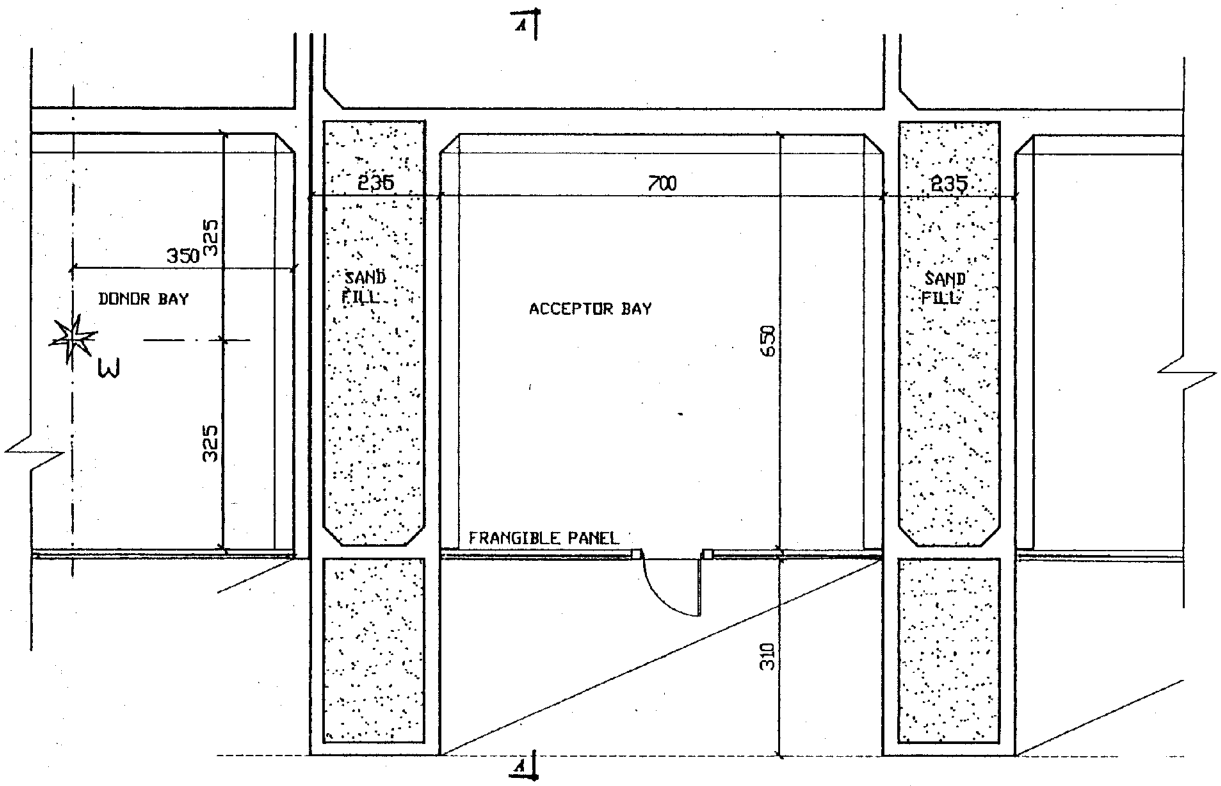

FIGURE 1b : LAYOUT OF THE SIMULATED SYMMETRICAL HALF

Figure 1c: Typical Cross-section of a Cubicle

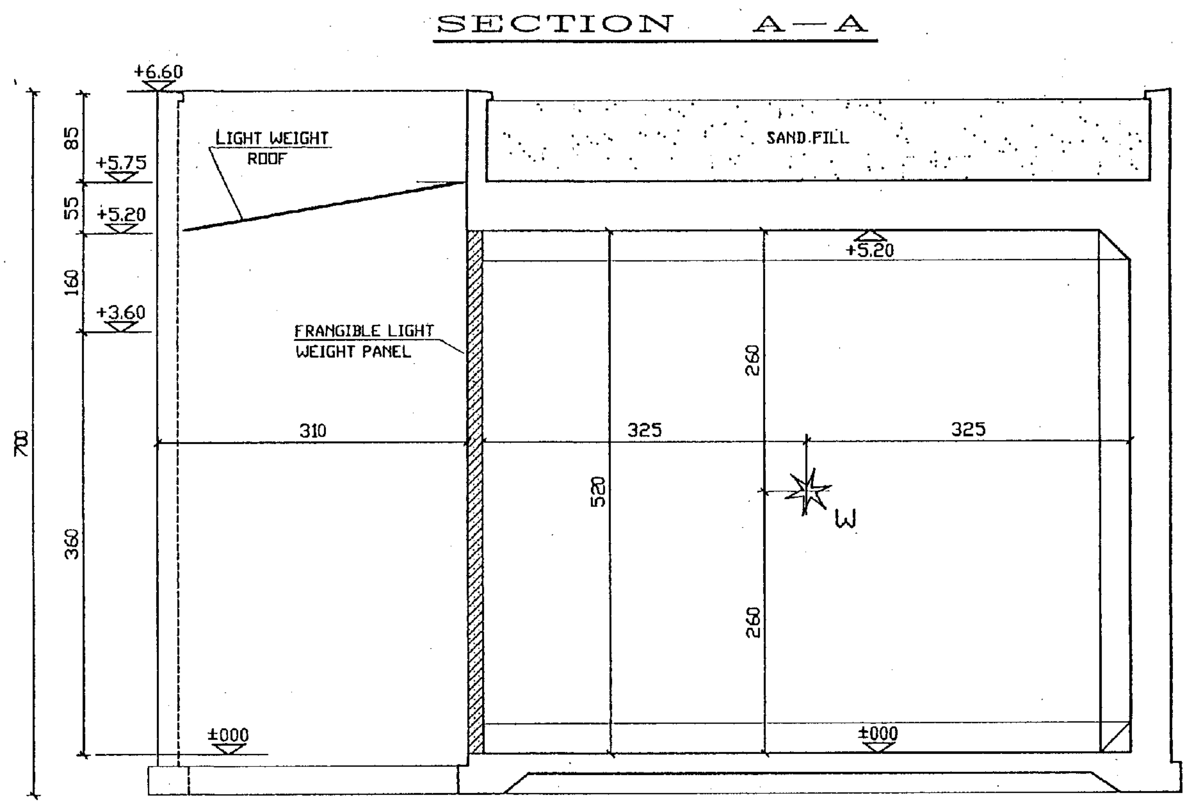

FIGURE 1c : TYPICAL CROSS-SECTION OF A CUBICLE

Figure 2a: Computational Mesh Showing Separation walls and Ceiling

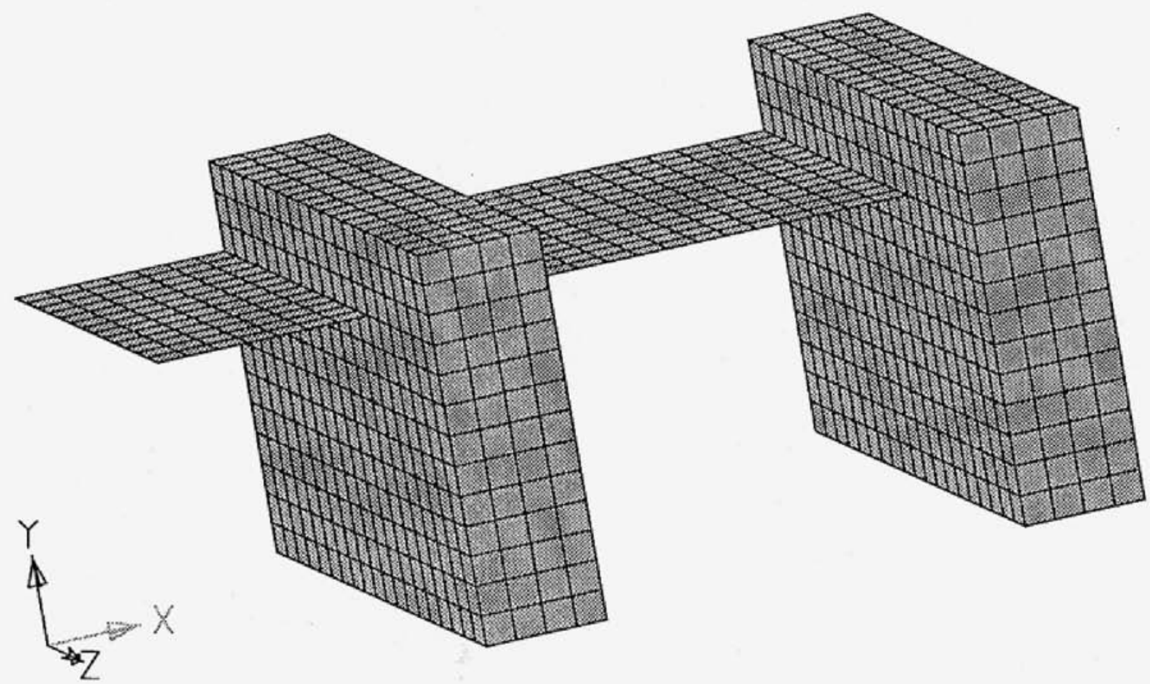

FIGURE 2a : COMPUTATIONAL MESH SHOWING SEPARATION WALLS AND CEILING

Figure 2b: Computational Mesh Showing Panels and Roofs

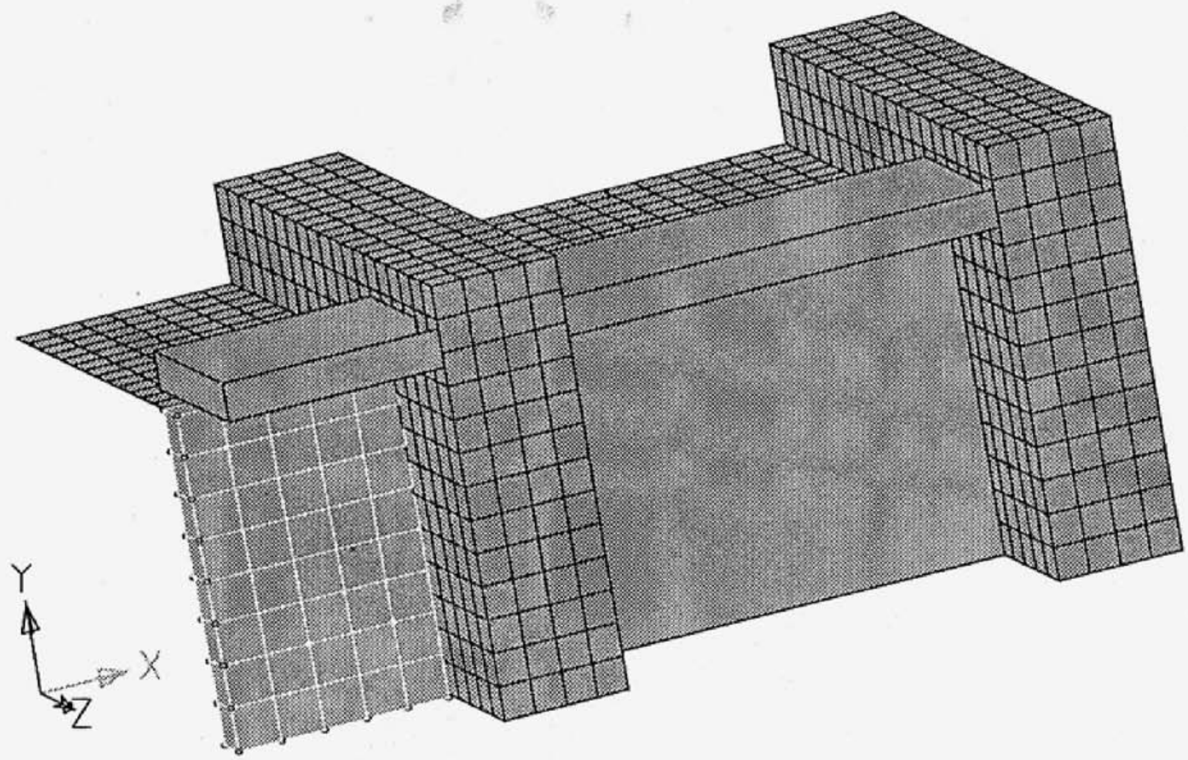

FIGURE 2b : COMPUTATIONAL MESH SHOWING PANELS AND ROOFS

Figure 3: Position of Roofs and Panels at Time = 100 Milliseconds

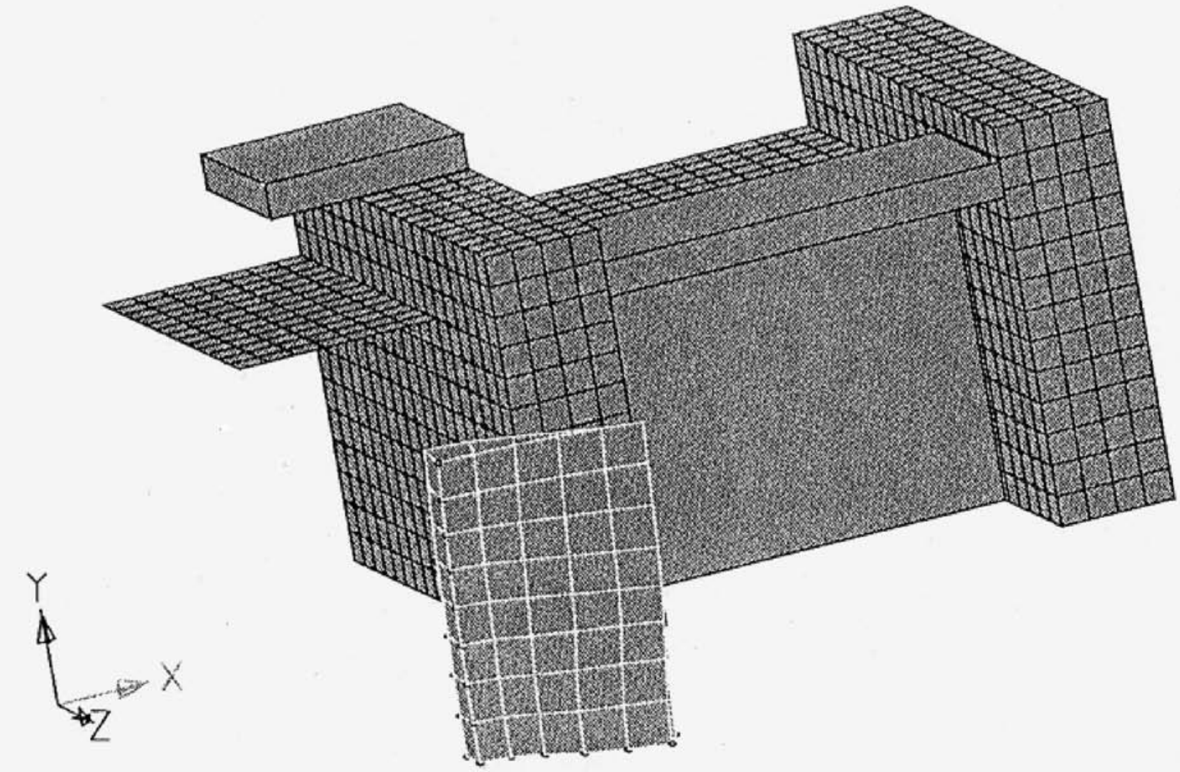

FIGURE 3 : POSITION OF ROOFS AND PANELS AT TIME = 100 MILLISECONDS

Figure 4: Velocity of Acceptor Panel vs. Time

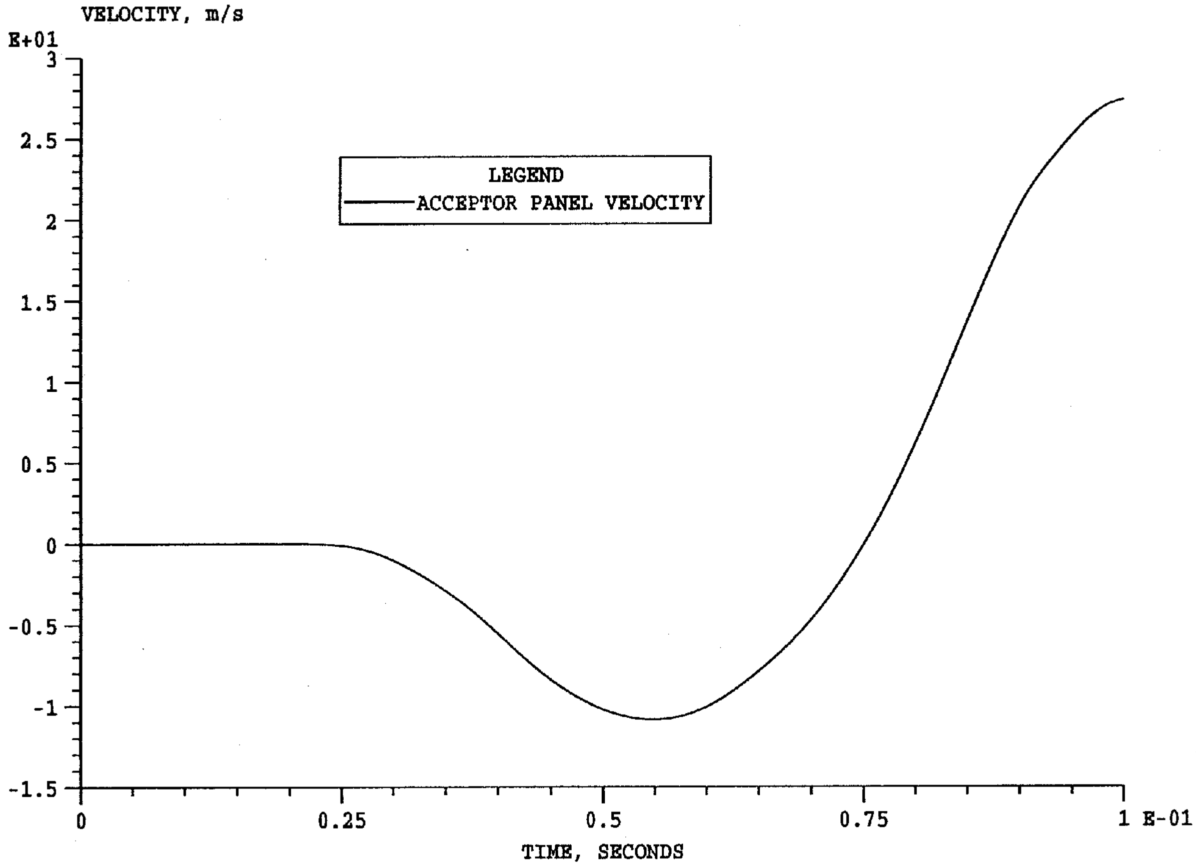

FIGURE 4 : VELOCITY OF ACCEPTOR PANEL VS. TIME